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Body mass index trajectory across childhood and subsequent risk of elevated blood pressure

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Abbreviations: BMI, body mass index; BP, blood pressure; CI, confidence interval; DBP, diastolic blood pressure; OR, odds ratio; SBP, systolic blood pressure.

Keywords: body mass index; trajectory; childhood; blood pressure

Abstract

We investigated the relationship between the body mass index (BMI) trajectory across childhood and the subsequent occurrence of elevated blood pressure (BP) in the Chinese pediatric population. The study cohort from the China Health and Nutrition Survey comprised 1484 children, each of whom underwent three BP and BMI

assessments during childhood and had a non-elevated BP during the first childhood assessment. A group-based trajectory model was used to identify four distinct BMI trajectories across childhood: lean–stable increase, medium–marked increase, heavy–marked decrease, and heavy–marked increase. Elevated BP in childhood was as defined in the China’s national BP reference for children. Covariate-adjusted logistic regression models were used to assess the associations of BMI trajectories with elevated BP. Overall, 27.6% of all participants between 3 and 13 years of age during the first childhood assessment developed elevated BP during a mean 6.5-year follow-up. Compared with participants in the lean–stable increase group, those in the medium–marked increase and heavy–marked increase groups were more likely to have elevated BP [odds ratio (95% confidence interval), OR (95%CI): 1.46 (1.08, 1.96) and 5.29 (2.44, 11.48), respectively; $P_s < 0.05$]. The OR for the heavy–marked decrease group was not statistically significant [OR (95%CI): 1.58 (0.80, 3.13); $P = 0.192$]. In summary, distinct BMI trajectories conferred significantly different odds of elevated BP upon children, thus underscoring the importance of weight management in early life.

Keywords: body mass index; trajectory; childhood; blood pressure

1. Introduction

The increasing prevalence of elevated blood pressure (BP) in childhood has become a global public health crisis.¹ An increasing body of evidence demonstrates the immediate effects of childhood elevated BP on the cardiovascular system.² Previous publications have also reported the long-term effects of elevated BP in childhood on adult cardiovascular health.^{3,4} In other words, the importance of preventing childhood elevated BP has long been recognized.⁵

Epidemiological studies indicate that excess weight in childhood is an important determinant of the onset and development of elevated BP in childhood.^{6,7} However, most studies that investigated the associations of childhood body mass index (BMI) with future adverse health consequences measured the BMI at only one time during childhood. This study design ignores the effects of the trajectory patterns of childhood

BMI over time (i.e., dynamic changes in size).⁸ Statistical techniques have been developed to identify the heterogeneity of BMI trajectories in given populations.^{9,10} Longitudinal studies have shown that different childhood BMI trajectory patterns confer significantly different risks of future adverse health consequences.¹¹⁻²⁰ However, few similar studies have been conducted in the Chinese pediatric population. Childhood BMI trajectory patterns and their association with health consequences may vary among populations.⁸ It is therefore necessary to clarify the elevated BP risks faced by Chinese children with distinct BMI trajectories across childhood. We hypothesized that in comparison with individuals who maintained a lean body shape across childhood, those who gained a substantial amount of weight or maintained excess weight would be more likely to have elevated BP while those who experienced weight loss would not be more likely to have elevated BP.

In this study, we used a group-based trajectory model to evaluate the association between the BMI trajectory across childhood and the consequent occurrence of elevated BP using data from the China Health and Nutrition Survey (CHNS).

2. Methods

2.1 Study population

The CHNS was a longitudinal epidemiological study. The survey procedures have been detailed elsewhere.²¹ Briefly, the CHNS was initiated in 1989 to examine nutrition and health status across China during a period of rapid urbanization. Subsequent surveys were conducted at 2–4-year intervals until 2015. The eligible survey data for our study were collected in 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011, and 2015. During each survey, BP, height, and weight measurements were obtained, and questionnaire surveys were conducted. A multistage random-cluster design was used to capture the study sample. The CHNS was approved by the institutional review boards of the University of North Carolina at Chapel Hill, the Ministry of Health of the People's Republic of China, and the National Institute for Nutrition and Health, Chinese Center for Disease Control and Prevention. All participants provided signed informed consent.

The CHNS included 1900 participants who underwent at least three assessments during childhood (<18 years). We excluded 134 participants without records of BP or BMI in childhood and 282 participants with elevated BP according to China's national BP reference at the first assessment.²² The final analysis sample consisted of 1484 participants aged 3 to 13 years during the first childhood assessment. To account for differences in the participants' ages at each assessment, we excluded data collected from participants during adulthood (age ≥ 18 years) to examine the association of BMI trajectory with subsequent elevated BP in childhood. As a result, 1242, 238, and 4 participants underwent 3, 4 and 5 assessments during childhood, respectively. To establish a stable childhood BMI trajectory, we analyzed three former assessments per participant in this study.

2.2 General examinations

At each assessment, trained physicians used standard mercury sphygmomanometers to measure the BP three times on the right arm after 10 minutes of seated rest. The first and fifth Korotkoff sounds were recorded as the systolic BP (SBP) and diastolic BP (DBP), respectively. The average of the last two readings was used in the analyses.

Height and weight were measured without shoes to the nearest 0.1 cm and with light clothing to the nearest 0.1 kg, respectively. The BMI was calculated as the weight in kilograms divided by the height in meters-squared.

Each participant's sex, age, and living area (urban/rural) were self-reported at each assessment. The follow-up duration was calculated as the elapsed time between the survey years corresponding to the first and third assessments.

2.3 Definitions

Elevated BP in childhood was defined as BP $\geq 120/80$ mm Hg or 90th percentile by sex, age, and height (whichever is lower) as per China's national BP reference for children, which was established based on a nationwide reference population.²² Childhood overweight (including obesity) was as defined in the International Obesity

Task Force recommendation.²³

2.4 Statistical analysis

We identified subgroups that followed similar BMI progressions over time across childhood by using a group-based trajectory model generated via SAS Proc Traj, as previously described in detail.^{9,10} In brief, the maximum likelihood method was used to fit the longitudinal data on BMI in a censored normal model with a polynomial function of age.⁹ The optimal model was determined using the Bayesian information criterion (BIC), mean posterior probabilities for each group (>0.8), membership of each group (we required each group to include more than 1% of all participants), and visual inspection of the patterns.^{10,18}

The data were presented as means (SDs) or frequencies (%). Comparisons between BMI trajectory groups were performed with an analysis of variance for continuous variables and with the χ^2 test or Fisher's exact test for categorical variables. We used linear and logistic regression models to assess the associations of the BMI trajectory across childhood with BP levels and elevated BP at the third assessment after adjusting for sex, living area, age and BMI at the first assessment, and follow-up duration, respectively.

All statistical analyses were conducted using SAS 9.4. We considered a two-sided *P* value of less than 0.05 to indicate statistical significance.

3. Results

Table 1 summarizes the characteristics of all participants at three childhood assessments during a mean 6.5-year follow-up period (range, 4–13 years). A total of 1484 children between 3 and 13 years of age had a non-elevated BP during the first childhood assessment. The prevalence of elevated BP was 13.3% and 27.6% during the second and third childhood assessments, respectively.

Using a group-based trajectory model to identify subgroups that followed similar BMI progressions over time across childhood, we found that the best-fitting model had four trajectories and a cubic function of age. The selection of the best-fitting model is

presented in Table S1 and Figure S1. Briefly, models with four and five trajectories had markedly better model fits than other models with two and three trajectories based on BIC, but the models with five trajectories had poor discrimination. For example, in the model with five trajectories and a cubic function of age, we observed mean posterior probabilities for group 1 <0.8 (Table S1 and Figure S1). Furthermore, we also detected similar growth curves for multiple groups in the models with five trajectories. For example, in the model with five trajectories and a cubic function of age, the growth curve in group 1 was similar to that in group 2 (Figure S1). Additionally, we found that the model with four trajectories and a cubic function of age had markedly better model fits than other models with four trajectories and a linear or quadratic function of age based on BIC.

Table S2 demonstrates the details of the best-fitting model with four BMI trajectories and a cubic function of age. Based on the aforementioned best-fitting model, Figure 1 presents the four predicted BMI trajectories from ages 8 to 11 to 14 years, which were approximately the average ages at the first, second, and third childhood assessments, respectively. Based on the visual pattern, we designated the trajectories as lean-stable increase, medium-marked increase, heavy-marked decrease, and heavy-marked increase. Overall, 70.4% of the participants began at a low level and maintained a small increase in BMI across childhood (lean-stable increase group); 22.0% began at a moderate level and experienced a relatively rapid increase in BMI (medium-marked increase group); 5.1% started at a high level and exhibited a relatively rapid decrease in BMI (heavy-marked decrease group); and 2.5% started at a high level and experienced a relatively rapid increase in BMI (heavy-marked increase group). The mean posterior probabilities for lean-stable increase, medium-marked increase, heavy-marked decrease, and heavy-marked increase were 0.92, 0.81, 0.84 and 0.94, respectively, indicating good discrimination by this assignment of BMI trajectories.

Table 1 also describes the characteristics of the participants stratified by BMI trajectory. The participants in the heavy-marked increase group had higher SBP and

DBP levels than those in the other groups at the three childhood assessments ($P_s < 0.05$). This group also had the highest prevalence of elevated BP whereas the lean–stable increase group had the lowest prevalence at both the second and third assessments ($P_s < 0.05$).

Table 2 shows the relationship of the childhood BMI trajectory to BP levels and elevated BP at the third assessment. The individuals in the medium–marked increase and heavy–marked increase groups had higher SBP ($P_s < 0.001$) and DBP levels ($P_s < 0.001$), and were more likely to have elevated BP at the third assessment [odds ratio (95% confidence interval), OR (95%CI): 1.46 (1.08, 1.96) and 5.29 (2.44, 11.48), respectively; $P_s < 0.05$] than those in the lean–stable increase group. In contrast, those in the heavy–marked decrease group did not have higher BP levels ($P_s > 0.05$) and were not more likely to have elevated BP [OR (95%CI): 1.58 (0.80, 3.13); $P = 0.192$] at the third assessment. These associations were independent of covariates, including sex, living area, age and BMI at the first assessment, and the length of follow-up.

Sensitivity analyses were performed to test the robustness of our findings. First, we used all available data, which included 3, 4, and 5 assessments in childhood for 1242, 238, and 4 participants, respectively. We established similar BMI trajectories across childhood and obtained similar results (Table S3). Second, sex and age at the first childhood assessment may influence the probability of belonging to a group. We fitted the BMI trajectories over time after adjustment for sex and age on the first childhood assessment, and examined the difference in group classification compared with the original BMI trajectory assignment. We found that 98.5% of all participants were reclassified into the same BMI trajectory groups, indicating the excellent stability of the original BMI trajectory assignment. We repeated the analyses with similar results (Table S4). Third, we calculated BMI z-scores after adjustment for sex and age by regression residual analyses.^{3,24} We analyzed the association of changes in the BMI z-scores from the first to third assessments with elevated BP and obtained similar results (Table S5).

4. Discussion

In this study, we identified four patterns of BMI trajectory over time across childhood. By comparing the risk of elevated BP among the groups of children with these four patterns, we determined that the participants in the heavy–marked increase group had the highest risk, whereas those in the lean–stable increase group had the lowest risk. Notably, those in the heavy–marked decrease group were not more likely to have elevated BP relative to the lean–stable increase group. Our findings confirm that monitoring of BMI trajectories across childhood could help to identify individuals with an increased risk of elevated BP in early life.

Interest in the heterogeneity of childhood BMI trajectory patterns has increased in response to the epidemic of pediatric overweight and obesity.²⁵ Cohort studies have confirmed that distinct BMI trajectories from childhood to early adulthood are related to various adult cardiometabolic risks.^{13,15,18,19} Moreover, the Nurses' Health Study and Health Professionals Follow-up Study also found that participants with distinct BMI trajectory groups from childhood and throughout the lifespan exhibited different levels of type 2 diabetes, cardiovascular disease (CVD), and mortality risk.^{11,12}

Childhood is a key period for the primordial prevention of CVD and related premature death.⁵ Therefore, evidence regarding the association between BMI trajectory patterns and cardiometabolic risks in childhood is needed to facilitate the early identification of children at high risk. Our study demonstrated that children who had a heavy or medium BMI at an early age and gained a substantial amount of weight over time were more likely to have elevated BP. In contrast, children who began at a heavy BMI but then lost the excess weight were not more likely to have elevated BP than those who maintained a lean body shape with a slight increase in weight. Previous studies of participants from various ethnic backgrounds across childhood also used group-based trajectory models to fit the BMI trajectory patterns and obtained similar associations with the risks of elevated BP and cardiometabolic disorders.^{14,16,17,20} Our main results (Table 2) and findings of sensitivity analyses (Table S5) were consistent

with those of several studies that assessed the weight status at only two time points in early life and presented the relationships between changes in the weight status and subsequent risks of hypertension and cardiometabolic disorders.^{24,26,27} In summary, most evidence confirms the critical deleterious cardiovascular effects of a substantial weight gain and excess weight maintenance and the benefits of weight loss across childhood.

Our study had several notable limitations. First, we did not adjust for smoking, drinking, physical activity, and nutrition during childhood in our analyses of the association between the BMI trajectory and elevated BP due to a lack of data. Second, our study cohort was limited to participants for whom data from three former pediatric assessments were available, which may have affected our established childhood BMI trajectories. However, the number of available assessments required to fit the trajectories remains uncertain.⁸ To address this limitation, we also performed sensitivity analyses based on all available data and obtained similar results (Table S3). Third, we did not present sex-specific BMI trajectories due to the insufficient sample size. However, we performed BMI trajectories adjusting for sex and age on the first childhood assessment, and found similar findings of BMI trajectories in relation to elevated BP (Table S4). Finally, the OR for the heavy-marked decrease group was relatively large but not statistically significant, which may be attributable to the small sample size. Further cohort studies are needed to clarify this issue given its clinical significance.

In conclusion, our results suggest that different childhood BMI trajectories conferred significantly different odds of elevated BP. These findings highlight the importance of weight management during early life in terms of the primordial prevention of CVD.

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Table 1. Characteristics of the participants across three childhood assessments

	All participants (n=1484)	BMI trajectory across childhood				P
		Lean-stable increase	Medium-marked increase	Heavy-marked decrease	Heavy-marked increase	
		(n=1045)	(n=327)	(n=75)	(n=37)	
Male (%)	53.5	52.9	55.7	48.0	62.2	0.427
Urban (%)	27.4	25.1	34.6	26.7	32.4	0.008
First assessment						
Age (years)	8.1 (1.5)	8.2 (1.5)	8.2 (1.6)	7.8 (1.6)	7.6 (1.8)	0.030
BMI (kg/m ²)	15.6 (2.2)	14.9 (1.3)	16.3 (1.5)	20.6 (3.6)	19.6 (2.9)	<0.001
Overweight and obesity (%)	6.5	1.1	4.0	66.7	62.2	<0.001
SBP (mm Hg)	86.9 (9.4)	86.4 (9.0)	88.3 (9.3)	86.1 (11.9)	91.5 (11.5)	<0.001
DBP (mm Hg)	56.2 (7.7)	55.8 (7.6)	57.4 (7.3)	55.5 (8.6)	58.4 (9.1)	0.002
Second assessment						
Age (years)	11.0 (1.6)	11.1 (1.6)	11.0 (1.6)	10.7 (1.9)	10.4 (1.7)	0.026
BMI (kg/m ²)	16.8 (2.5)	15.8 (1.6)	18.6 (2.1)	20.1 (2.4)	23.3 (2.9)	<0.001
Overweight and obesity (%)	6.5	0.4	8.9	42.7	86.5	<0.001
SBP (mm Hg)	95.1 (11.9)	94.0 (11.5)	97.3 (11.8)	96.3 (12.5)	103.2 (14.9)	<0.001

DBP (mm Hg)	62.5 (8.9)	62.0 (8.9)	63.9 (8.7)	62.3 (9.0)	66.1 (11.2)	<0.001
Elevated BP (%)	13.3	11.7	14.7	21.3	29.7	0.001
Third assessment						
Age (years)	14.6 (1.5)	14.6 (1.5)	14.6 (1.5)	14.3 (1.8)	14.1 (1.5)	0.085
BMI (kg/m ²)	19.0 (2.6)	18.0 (1.8)	21.3 (1.7)	19.9 (1.9)	26.4 (3.2)	<0.001
Overweight and obesity (%)	4.2	0.1	8.6	1.3	86.5	<0.001
SBP (mm Hg)	104.4 (11.2)	103.0 (10.8)	107.3 (11.1)	106.0 (10.6)	114.7 (13.1)	<0.001
DBP (mm Hg)	68.5 (8.7)	67.4 (8.7)	70.7 (8.0)	69.7 (8.0)	76.0 (11.2)	<0.001
Elevated BP (%)	27.6	24.7	32.1	32.0	59.5	<0.001

BMI, body mass index; BP, blood pressure; DBP, diastolic blood pressure; SBP, systolic blood pressure.

Data are presented as means (SDs), or frequencies (%) as appropriate.

Differences for continuous variables and categorical variables were compared using the analysis of variance and χ^2 test or Fish's exact probabilities, respectively.

Table 2. Childhood BMI trajectory in relation to BP levels and elevated BP on the third assessment

	Outcome: SBP		Outcome: DBP		Outcome: elevated BP	
	β (SE) *	P	β (SE) *	P	OR (95% CI) *	P
Lean-stable increase	Ref		Ref		Ref	
Medium-marked increase	4.147 (0.717)	<0.001	2.977 (0.562)	<0.001	1.46 (1.08-1.96)	0.013
Heavy-marked decrease	2.719 (1.633)	0.096	1.655 (1.280)	0.196	1.58 (0.80-3.13)	0.192
Heavy-marked increase	11.660 (1.969)	<0.001	8.368 (1.544)	<0.001	5.29 (2.44-11.48)	<0.001

BMI, body mass index; BP, blood pressure; DBP, diastolic blood pressure; SBP, systolic blood pressure; β , unstandardized regression coefficients; CI, confidence interval; OR, odds ratio.

*Adjusted for sex, living area, age on the first assessment, the length of follow-up, and BMI on the first assessment.

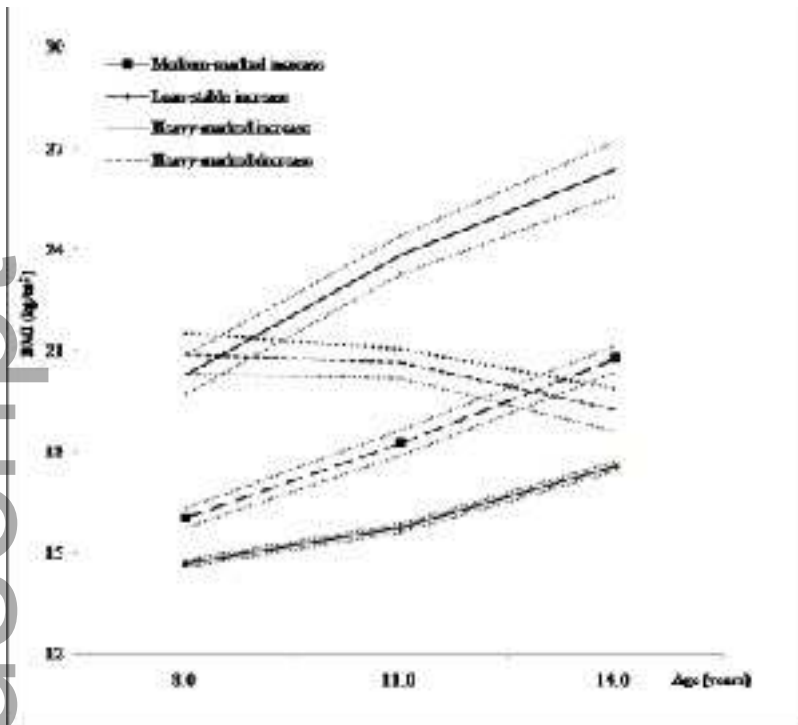


Fig 1 Trajectories of BMI across childhood
BMI, body mass index. Dashed lines are 95% confidence interval lines.

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